68/F

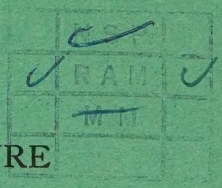
Publication 1022 March, 1958

STUDIES IN FOREST PATHOLOGY

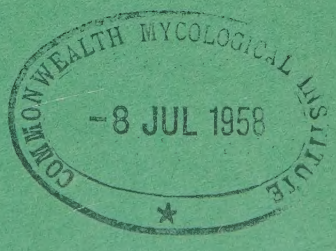
XVII

THE PATHOLOGICAL DETERIORATION OF FIRE-KILLED PINE IN THE MISSISSAGI REGION OF ONTARIO

by
J. T. BASHAM



FOREST BIOLOGY DIVISION
CANADA DEPARTMENT OF AGRICULTURE
OTTAWA, ONTARIO



Studies in Forest Pathology

I. Decay in Balsam Fir (*Abies balsamea* Mill.). *By A. W. McCallum* - 1928

II. The Biology of *Fomes pinicola* (SW.) Cooke. *By Irene Mounce* - - 1929

III. *Hypoxylon* Canker of Poplar. *By J. E. Bier* - - - - - 1940

IV. Decay of Sitka Spruce on the Queen Charlotte Islands. *By J. E. Bier, R. E. Foster, and P. J. Salisbury* - - - - - - - - 1946

V. Decay in Fir, *Abies lasiocarpa* and *A. amabilis*, in the Upper Fraser Region of British Columbia. *By J. E. Bier, P. J. Salisbury, and R. A. Waldie* - - - - - - - - - - - - - 1948

VI. Identification of Cultures of Wood-rotting Fungi. *By Mildred K. Nobles* 1948

VII. Decay in Western Hemlock and Fir in the Franklin River Area, British Columbia. *By D. C. Buckland, R. E. Foster, and V. J. Nordin* - - - 1949

VIII. Decay of Western Hemlock on the Queen Charlotte Islands, British Columbia. *By R. E. Foster and A. T. Foster* - - - - - - - 1951

IX. *Fomes igniarius* Decay of Poplar. *By C. G. Riley* - - - - - 1952

X. Decay of White Pine in the Timagami Lake and Ottawa Valley Areas. *By L. T. White* - - - - - - - - - - - - 1953

XI. Decay in Black Cottonwood in the Middle Fraser Region, British Columbia. *By G. P. Thomas and D. G. Podmore* - - - - - - 1953

XII. Decay of Western Hemlock in the Upper Columbia Region, British Columbia. *By R. E. Foster, H. M. Craig, and G. W. Wallis* - - - 1954

XIII. Decay in Sugar Maple in the Ottawa-Huron and Algoma Extension Forest Region of Ontario. *By Vidar J. Nordin* - - - - - - 1954

XIV. Decay of Douglas Fir in the Coastal Region of British Columbia. *By G. P. Thomas and R. W. Thomas* - - - - - - - - - 1954

XV. Rootlets, Mycorrhiza, and Soil Temperatures in Relation to Birch Dieback. *By D. R. Redmond* - - - - - - - - - - 1955

XVI. Decay of Balsam Fir, *Abies balsamea* (L.) Mill., in the Atlantic Provinces. *By A. G. Davidson* - - - - - - - - - 1957

Publication 1022 March, 1958

STUDIES IN FOREST PATHOLOGY

XVII

The Pathological Deterioration of Fire-killed Pine in the Mississagi Region of Ontario

by
J. T. BASHAM

CANADA DEPARTMENT OF AGRICULTURE
OTTAWA, ONTARIO

2M–23246—3 : 58
97393-3—1

TABLE OF CONTENTS

	Page
Introduction	5
Location of Work	7
Choice of Study Areas	7
Methods of Study	7
Field Procedure	7
Office Tabulations	10
Causes of Tree Deterioration	10
Fungal Deterioration	11
Sap Stain and Sap Rot	11
Heart Rot	17
Factors that May Influence the Rate of Deterioration	21
Tree Growth Rate and Diameter	21
The Degree of Burn	24
The Deterioration of Jack, Red, and White Pine Trees	24
The Deterioration of Jack Pine and Red Pine Stands	29
Pulpwood Losses in Fire-killed Jack Pine	35
Discussion	35
Acknowledgments	37
References	37

Digitized by the Internet Archive
in 2025

https://archive.org/details/publications-canada-department-agriculture_1958-03_1022

The Pathological Deterioration of Fire-killed Pine in the Mississagi Region of Ontario

by J. T. Basham[1]

Introduction

On May 25, 1948, two fires were reported in the Mississagi-Chapleau district of Ontario. By the end of June, some 645,000 acres with forests composed mainly of valuable pine had been swept by the flames. Vast stands of dead, charred pine, spruce, and birch remained. In a brief period of five weeks a considerable portion of the dwindling reserves of white and red pine in the Province had been killed—but not destroyed. Forestry officials realized that in a few years these trees would be reduced to a worthless condition by various agents of deterioration. With this in mind, under government supervision, extensive salvage operations commenced in November, 1948. Practically all the cutting operations took place during the period 1948 to 1952, and over 300 million board feet of pine lumber was eventually recovered.

The task of salvaging large areas of dead timber is, as a rule, a formidable one, though there are a few advantages for the operator. The lighter weight of dried logs results in small sinkage losses and lower truck and rail transportation costs. The tremendous disadvantages that inevitably confront the operator, however, often constitute insuperable obstacles to extensive operations. These obstacles include the sometimes vast and inaccessible burned areas, the limited time during which much of timber remains in a suitable merchantable condition, the dependence upon ready markets, the excessive breakages that commonly occur in felling dead timber, and the extensive losses from deterioration caused by insects and fungi.

The intensity of insect attack and the rate at which fungal deterioration progresses will determine the period in which economical salvage is possible. The more knowledge that is available concerning the nature, causes, and rate of deterioration of these trees, the easier the formulation of intelligent workable operating plans. The reduction in quality and value of the salvaged timber at various intervals following the death of the trees should be estimated as accurately as possible in order that these plans will ensure that the maximum amount of wood is recovered in the most profitable manner.

Although there have been a number of studies made of the deterioration of fire-killed timber in North America (4, 6, 7, 8, 12, 13), none has dealt extensively with red and white pine. Members of the Forest Pathology Laboratory, Maple, and the Forest Insect Laboratory, Sault Ste. Marie, as well as officers

[1]Laboratory of Forest Pathology, Southern Research Station, Maple, Ontario.

97393–3—2

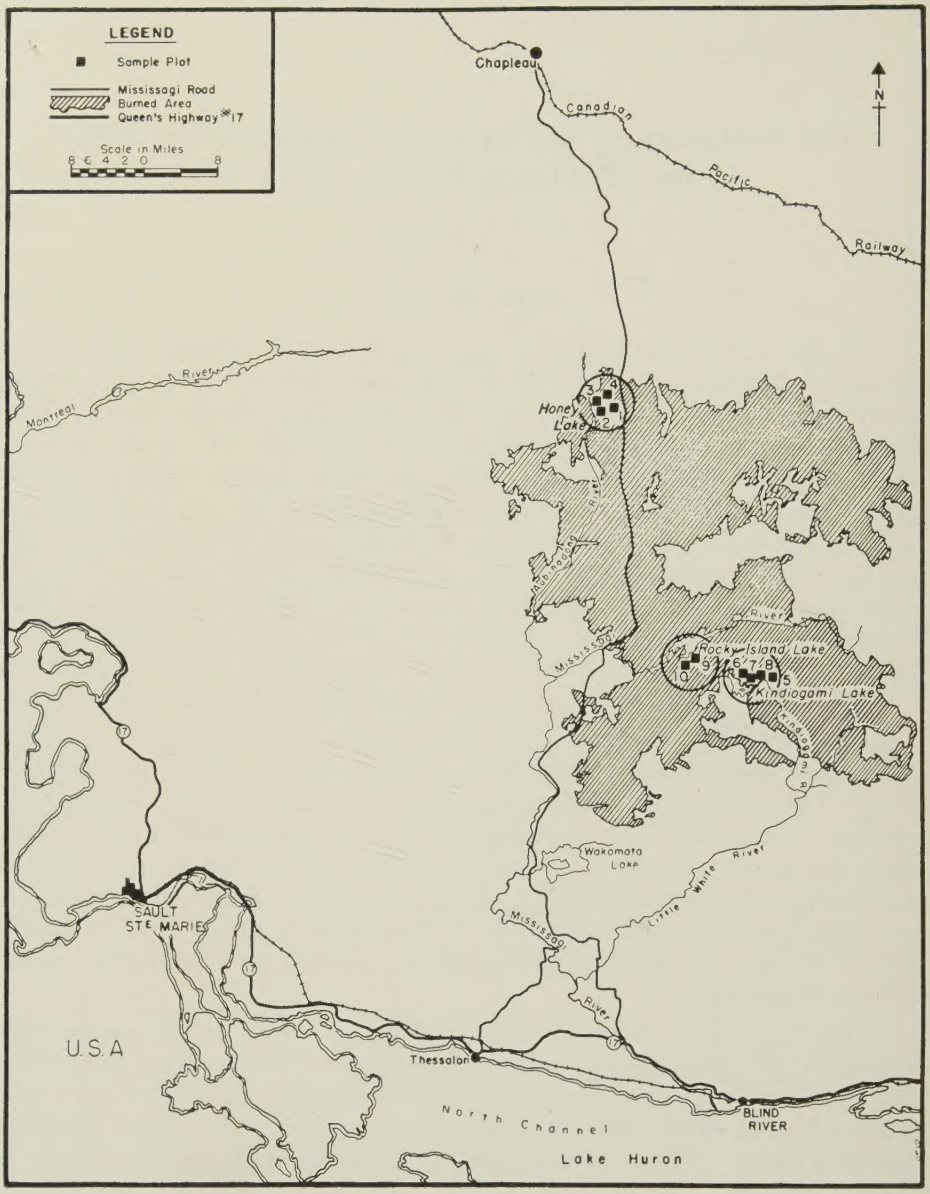


FIGURE 1. Map of burned area illustrating the location of sample plots.

of the Ontario Department of Lands and Forests, were eager to take advantage of this opportunity to collect information concerning the practicability and probable duration of profitable salvage operations in stands of this type. Furthermore, provincial government officials hoped to secure information that would serve as a guide in determining the extent to which Crown dues should be adjusted on salvaged, fire-killed pine timber.

Location of Work

The approximate area in which tree mortality occurred in the 1948 Mississagi fire and the location of each of the ten sample plots are shown in Fig. 1. A general description of each plot, including the frequency of occurrence of the three species of pine and the degree of burn, is presented in Table I.

Records of pathological deterioration were made of individual fire-killed red and white pine trees at two sites near Lake Kindiogami in Township 3B, roughly 50 miles northeast of Thessalon. Four permanent sample plots were established in burned-over jack pine stands in the area north of Honey Lake in Township 8E, about 40 miles south of Chapleau. Four plots were also set up in burned-over red pine stands at Lake Kindiogami, and two more were later established in burned-over red pine stands at Rocky Island Lake. These six red pine plots were 30 to 35 miles southeast of the four jack pine plots at Honey Lake.

Choice of Study Areas

In November, 1949, Dr. M. L. Prebble, then Officer-in-Charge of the Forest Insect Laboratory, Sault Ste. Marie, and colleagues, carried out a mill study of the extent of degrade due to insects and sap stains in logs from representative burned white pine, red pine, and jack pine trees. The results of this study (11) indicated an average loss in value of 27.5 per cent for white pine logs, 11.2 per cent for red pine logs, and 4.8 per cent for jack pine logs. The prevailing opinion in the spring of 1950 was that this high degrade figure for white pine would seriously restrict any further salvage of this species. Hence, it was decided to investigate only those burned stands composed mainly of jack pine or red pine, although data were to be collected from white pine occurring on the plots established in those stands.

Sample plots, usually one or two acres in size, were established in jack pine and red pine stands of varying degrees of burn. Representative areas of these stands are illustrated in Figs. 2 to 7. The severity of burn was judged on the basis of the ratio of surviving and dead trees, the extent of charring and loosening of the bark, the condition of the branches, and the presence or absence of the discolored foliage of killed trees.

Variations in site type were not considered in the selection of areas to be sampled, as practically all pine stands in the burned region occur on sandy, well-drained, undulating sites of a fairly uniform nature. Furthermore, it was felt that slight variations in site among the sample plots would not appreciably affect the rate of deterioration of the killed trees.

Methods of Study

Field Procedure

In the year following the fire, information concerning the extent of sap stain in red and white pine trees was obtained from individual trees dissected by officers of the Forest Insect Laboratory.

97393–3—2½

TABLE I

DESCRIPTION OF SAMPLE PLOTS

Plot number (1)	Predominant merchantable species (2)	Location (3)	Plot area in acres (4)	Year of plot establishment (5)	Pine trees of merchantable size				Average D.B.H.* of merchantable pine trees (10)	Age class of pine at time of burn (11)	Estimated degree of burn (12)
					Jack pine (6)	Red pine (7)	White pine (8)	Total (9)			
1	Jack pine	Honey Lake	2.0	1950	96	0	25	121	13.4	150–160	Heavy
2	Jack pine	Honey Lake	2.0	1950	206	0	23	229	12.3	150–160	Medium
3	Jack pine	Honey Lake	1.75	1950	118	0	4	122	11.9	150–160	Heavy
4	Jack pine	Honey Lake	2.50	1950	219	0	1	220	10.3	70–80	Light
5	Red pine	L. Kindiogami	0.50	1950	3	41	3	47	15.3	140–150	Heavy
6	Red pine	L. Kindiogami	2.0	1950	5	158	49	212	14.2	140–150	Medium
7	Red pine	L. Kindiogami	1.25	1950	2	100	12	114	12.2	140–150	Light
8	Red pine	L. Kindiogami	0.75	1951	0	83	9	92	13.1	140–150	Medium
9	Red pine	Rocky Island L.	1.0	1952	5	78	22	105	14.9	140–150	Medium
10	Red pine	Rocky Island L.	1.0	1952	18	55	18	91	13.8	140–150	Heavy
Total			14.75		672	515	166	1,353			

*Diameter at breast height, outside bark.

FIGURE 2. View of lightly burned jack pine stand, Honey Lake, taken in 1950. Living trees are scattered throughout the stand.

FIGURE 3. View of severely burned jack pine stand, Honey Lake, taken in 1950.

FIGURE 4. View of lightly burned red pine stand, Lake Kindiogami, taken in 1950.

FIGURE 5. View of severely burned red pine stand, Lake Kindiogami, taken in 1950.

FIGURE 6. Lightly burned jack pine log with bark intact and very lightly charred.

FIGURE 7. Severely burned jack pine log with bark removed and some sapwood consumed.

By 1950 the recoverable merchantable volume of the killed pine trees began to decrease owing to the development of rot in the sapwood. Permanent sample plots were established at that time and were designed so that one-quarter of each might be examined in the four successive field seasons from 1950 to 1953.

Each of the merchantable pine trees on these plots was felled, dissected, and described as thoroughly as possible on logarithmic tree measurement forms. The degree of burn of each tree, based on visible characteristics, was noted, and the total merchantable volume before the fire was computed in accordance with the Ontario Manual of Scaling Instructions. In addition, the volumes of heart rot, sap rot, sap stain, and consumed wood were plotted as accurately as possible for each tree. Samples of the stains and rots encountered were shipped to the Maple Laboratory where cultures were made which were sent to the Botany and Plant Pathology Division, Ottawa, for the identification of fungi associated with the several defects.

Office Tabulations

The total volume and the total merchantable volume in cubic feet were computed for each tree from the areas representing these volumes on the logarithmic tree measurement forms. Similarly, the portions of the total merchantable volume occupied by heart rot, sap rot, sap stain, and consumed wood were determined.

The trees were scaled from the tree measurement forms and deductions were then made for both heart rot and sapwood deterioration in conformity with instructions presented in the Ontario Manual of Scaling Instructions. These calculations were carried out on a sawlog basis for all three species of pine. Jack pine trees were also scaled on a pulpwood basis.

The average depth of radial penetration of visible deterioration was computed for each tree. An analysis was made to determine whether any relationship existed between the depth of pathological deterioration and (a) tree diameter, (b) the average width of annual rings in the outer portion of the bole, and (c) the degree of burn.

Causes of Tree Deterioration

Immediately following even a severe fire, the reduction in the net merchantable volume of the stand is negligible. The killed trees remain suitable for the production of lumber and pulpwood with little or no reduction of grade until the agents of deterioration operate to reduce progressively the yield and quality of timber. Besides the slight immediate destruction of merchantable wood by the fire itself, the other deteriorating agents are fungal decay, insect attack, mechanical wear, and the destructive effects of exposure to all types of weather. Excessive breakage due directly to the fire may cause appreciable losses; apart from this one can disregard mechanical wear. The adverse effects of weather are of little significance compared with those of fungi and insects.

Evidence from other investigations indicates that, in stands of this type, there is a close association between the two principal agents of deterioration, insects and fungi (9). In most cases, insect activity precedes fungal attack, and the insects may play an important role in distributing the fungi to the host trees. Although most insect activity terminates within one or two years following the death of the tree, fungal deterioration often continues until the entire trunk is destroyed.

Fungal Deterioration

The fungi that alter the wood of dead trees may be divided into two groups based on time of attack and the portion of the tree affected. The first group is made up of those that attack dead trees, and because they initiate infection from the outer sapwood they are referred to as sap stain fungi or sap rot fungi. The second group includes those fungi that were already present in the heartwood of living trees and are commonly known as heart rot fungi. A few species belong to both groups. The deterioration caused by representatives of the two groups will be considered separately.

Sap Stain and Sap Rot

After death, the sapwood, previously capable of resisting the invasion of harmful fungi, becomes exceedingly susceptible to sap-staining and sap-rotting organisms. These fungi enter the outer bole using the many avenues through the bark present in dead trees. As a rule they advance through the wood until, eventually, almost all of the tree is infected. This process takes a few to many years, depending upon the various factors and conditions. In the interval between the death of the trees and complete destruction, decreasing amounts of perfectly sound, usable wood remain in the central portions of the boles. In many cases this wood can be profitably utilized in the production of lumber or pulpwood.

The fungi involved in this type of deterioration of fire-killed pine fall into two distinct groups, both taxonomically and according to the type of deterioration with which they are associated. Those fungi responsible for sap stains belong mainly to the group "Fungi Imperfecti"; those also causing sap rots are members of the Class Basidiomyceteae, order Agaricales.

Three different sap stains, designated as blue stain, brown stain, and orange-ring stain, as well as white and brown sap rots, were encountered in the fire-killed pine trees. Table II shows the annual volumetric occurrence of these five types of fungal deterioration in jack, red, and white pine from two to five years after the fire. The three sap stains are illustrated in Figs. 8 to 11.

Three fungi, not yet identified, were consistently isolated from wood affected by the three different stains. The growth of these sap stain organisms is dependent upon a relatively high moisture content in the wood, as they derive their nourishment from the cell sap rather than the cell walls (10). For these reasons they are limited to the sapwood and can exist only from one to three years following the death of the trees. They do not affect the strength

TABLE II.

THE ANNUAL FREQUENCY OF OCCURRENCE OF THE FIVE MAJOR TYPES OF FUNGAL DETERIORATION IN FIRE-KILLED JACK, RED, AND WHITE PINE

Type of deterioration	Percentage of trees affected											
	Jack pine—658 trees				Red pine—462 trees				White pine—156 trees			
	1950	1951	1952	1953	1950	1951	1952	1953	1950	1951	1952	1953
Blue stain	90.2	93.1	82.2	12.3	100.0	100.0	100.0	25.5	96.2	97.1	85.4	8.3
Brown stain	38.2	64.4	64.4	5.6	95.8	89.0	58.8	11.1	84.6	85.3	47.9	6.3
Orange ring stain	34.3	33.9	41.5	51.9	1.0	0.0	1.5	0.0	3.8	0.0	43.8	18.8
White sap rot	34.8	55.2	80.5	95.1	36.4	65.9	100.0	98.7	38.4	41.2	95.8	100.0
Brown sap rot	33.8	42.5	65.3	66.7	44.8	50.0	63.4	71.2	23.1	47.1	66.7	75.0

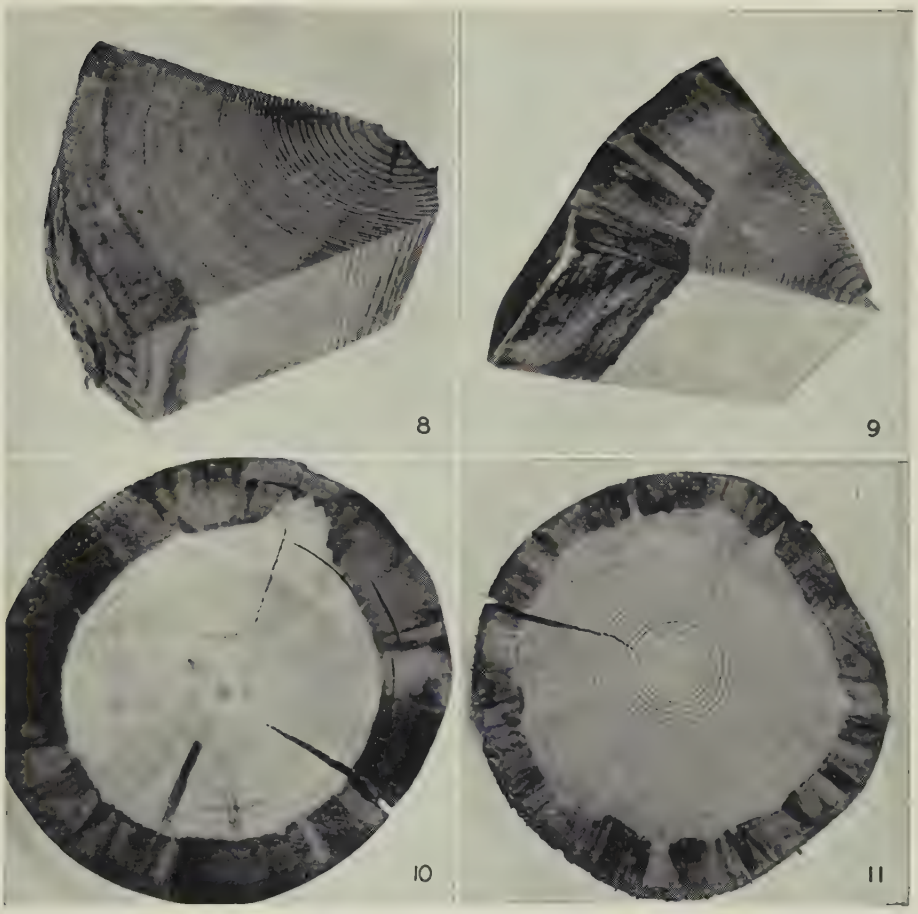


FIGURE 8. Orange-ring stain at junction of sapwood and heartwood in dead jack pine, two years after the fire.

FIGURE 9. Blue sap stain in dead jack pine, two years after the fire.

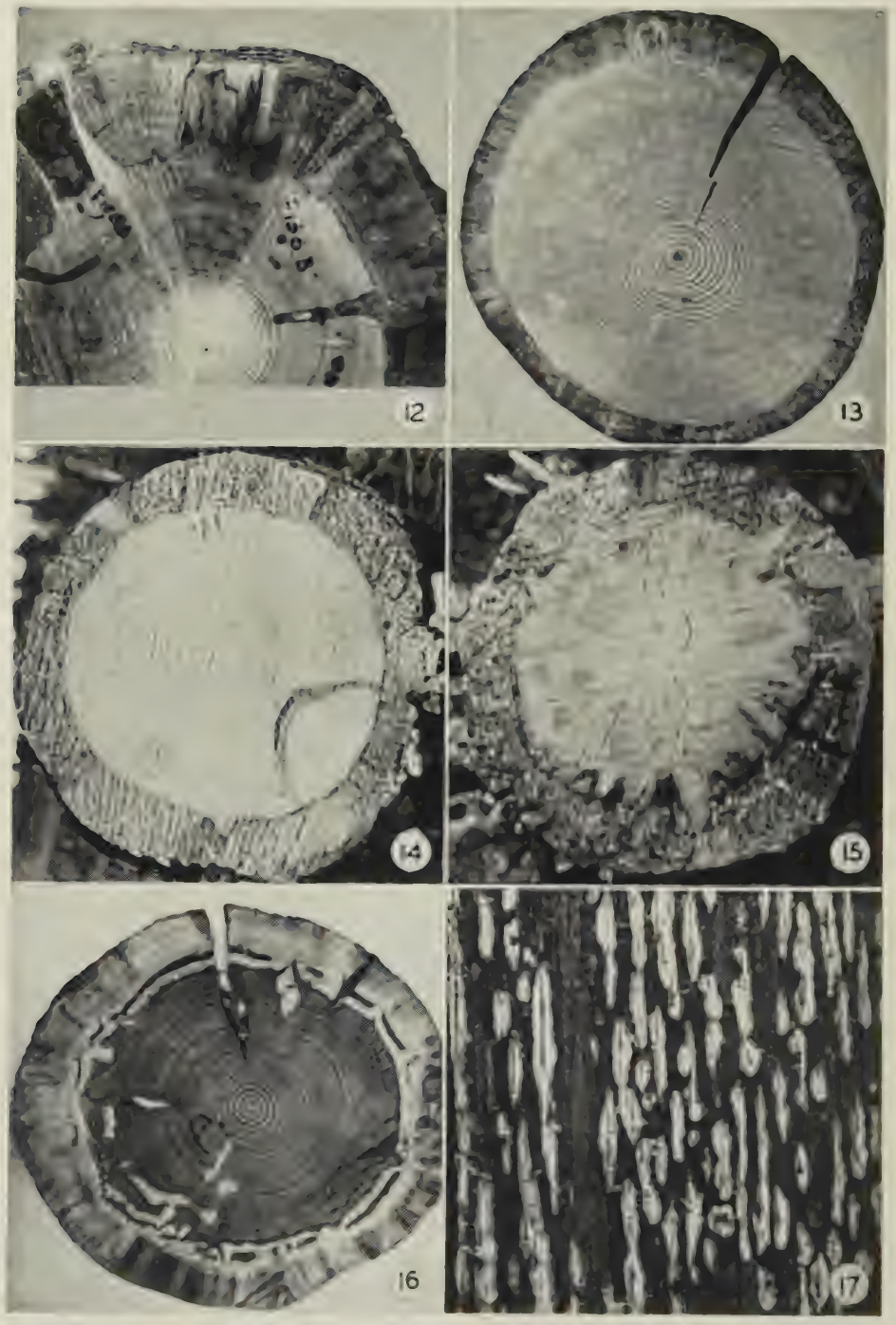
FIGURE 10. Blue and brown stained sapwood in a transverse section of red pine tree, two years after the fire.

FIGURE 11. Incipient sap rot and stained sapwood in a transverse section of red pine tree, three years after the fire.

of the wood to any appreciable extent. However, since the conditions favoring the growth of staining fungi also favor the growth of wood-destroying fungi, there exists a fairly strong prejudice against the use of stained wood. This prejudice is unwarranted except in cases where the appearance of stained wood would be objectionable or where strength is of considerable importance.

Blue stain was unquestionably the most extensive stain encountered. Most of the sapwood of all three species exhibited blue stain three years after the fire. Many cases of brown stain were noted in the sapwood of trees examined after they had been dead for one year. These appeared usually as patches in the rings of blue stain, although occasionally the situation was

97393—3—3



FIGURES 12 – 17.

reversed and a complete band of brown stain containing patches of blue stain occurred. It is possible that some of these brown stains were actually incipient stages of brown cubical sap rots. Boyce (3) states "brown sap stain . . . is confined to sapwood and is common on jack . . . and red pines, and . . . occasionally on . . . western white pines." Most of the organisms isolated from brown stained wood were identified as Fungi Imperfecti, and therefore this type of deterioration was classified as stain rather than as incipient rot.

The peculiar orange-ring stain observed in approximately half of the jack pine trees and in many white pine trees is of little economic importance. The ring, roughly one-quarter inch wide, occurs at or close to the dividing line between heartwood and sapwood, and was commonly observed in association with tunnels of *Monochamus* spp. wood borers. Although it has been definitely ascertained that this stain is caused by a species of the Fungi Imperfecti group, its obvious departure from the usual mode of occurrence of sap-staining fungi makes laboratory inoculation tests desirable.

The second group of organisms involved in this type of deterioration, those causing sap rots, differs from the sap-staining organisms in two important respects. First, their attack upon the cell walls results in a reduction of the strength properties and may ultimately destroy infected wood. Second, since they are not dependent upon living cells for nourishment they may continue to advance through the heartwood until all of the bole has been destroyed.

These wood-destroying fungi can be further subdivided into two groups, the "white rot" group which first decomposes the lignin leaving a residue mostly of cellulose; and the "brown rot" group which decomposes the cellulose and its associated substances, leaving the lignin practically unaffected. These two types of sap rot are illustrated in Figs. 12 to 15. The first group usually reduces the wood to a soft spongy or stringy mass, sometimes with a distinct pocket-like appearance. The color of this decayed wood varies from white to a yellowish buff. The second, or "brown rot", group of sap-rotting fungi reduces the wood to a brown crumbly mass which is often fractured into cubes that powder easily when crushed between the fingers.

The determination of the causal organisms of these sap rots was complicated by the fact that in many instances in 1950 and 1951 they were masked in culture by the sap-staining fungi with which they grew in close association.

FIGURE 12. Patches of brown cubical sap rot caused by *Fomes pinicola* in dead jack pine, two years after the fire.

FIGURE 13. White stringy and brown cubical sap rot in the outer sapwood in transverse section of a dead red pine tree, three years after the fire.

FIGURE 14. White stringy sap rot in entire sapwood portion of a jack pine tree, transverse section, four years after the fire.

FIGURE 15. Brown cubical sap rot in entire sapwood portion of a red pine tree, transverse section, five years after the fire.

FIGURE 16. *Fomes pini* heart rot in a red pine tree, transverse section, three years after the fire.

FIGURE 17. *Fomes pini* heart rot in a white pine tree, radial section.

97393–3—3½

TABLE III

FUNGI ISOLATED FROM SAP ROT IN FIRE-KILLED PINE TREES AND THEIR FREQUENCY OF OCCURRENCE

"WHITE" SAP ROTS	Total number of isolations	Annual percentages of isolations from white rots and brown rots											
		Jack pine				Red pine				White pine			
		1950	1951	1952	1953	1950	1951	1952	1953	1950	1951	1952	1953
Peniophora gigantea (Fries) Massee	170	14.8	35.6	34.6	14.3	65.0	69.2	40.0	33.9	60.0	9.1	8.3	17.6
Polyporus anceps Peck	135	11.1	45.7	44.3	30.6		11.5	25.7	18.7		45.4	29.2	23.5
Polyporus abietinus Dicks. ex Fries	104	59.3	5.1	11.5	22.5	20.0	7.7	18.0	16.1	40.0	36.4	54.2	35.3
Corticium galactinum (Fries) Burt	35				12.3			9.5	13.4			8.3	11.8
Poria subacida (Peck) Sacc.	14	11.1	1.7	3.9	4.1	10.0	3.9		1.8				5.9
Phlebia merismoides Fries	14	3.7		1.9				3.8	7.1				
Peniophora aspera (Pers.) Sacc.	5				2.0			1.0	2.7				
Trechispora brinkmannii (Bres.) Rog. and Jacks.	5				2.0	5.0	7.7		0.9				
Peniophora cinerea (Pers. ex Fries) Cooke	4		3.4		2.0						9.1		
Polyporus volvatus Peck	4							1.0	2.7				
Odontia bicolor (Alb. and Schw. ex Fr.) Bres.	3			1.9	4.1								
Polyporus dichrous Fries	2				2.0				0.9				
Polyporus borealis Fries	2								0.9				5.9
Claudopus nidulans Fries	2			1.9				1.0					
Poria rufa (Schrad. ex Fries) Cooke	1				2.0								
Poria notata Overh.	1				2.0								
Polyporus albellus Peck	1								0.9				
Total	502												
"BROWN" SAP ROTS													
Fomes pinicola (Sw.) Cooke	123	80.9	66.0	36.4	9.1	100.0	75.0	29.5	17.9	100.0	85.7	72.7	
Fomes subroseus (Weir) Overh.	39			6.1	22.7				74.4				75.0
Coniophora puteana (Schum. ex Fries) Karst.	38	4.8	10.0	24.2	13.6			29.5	5.1			9.1	
Lenzites saepiaria Wulf. ex Fries	32	9.5	18.0	27.3	18.2			9.8	2.6				25.0
Poria monticola Murr.	24	4.8	4.0	3.0			25.0	21.3			14.3	18.2	
Merulius himantioides Fries	11		2.0		22.7			8.2					
Peniophora phlebioides Jacks. and Deard.	2				9.1								
Corticium fuscostratum Burt	1			3.0									
Poria sinuosa (Fries) Cooke	1							1.7					
Polyporus guttulatus Peck	1				4.6								
Total	272												

Furthermore, sap rots were often difficult to trace because of their complex, patchy occurrence. Nevertheless, it is felt that the frequency with which various fungi were isolated from samples of sap rot, as shown in Table III, indicates the relative importance of these fungi in causing sap rot in fire-killed jack, red, and white pine. From Table III it is apparent that of the 17 organisms isolated from white sap rots, three fungi, *Peniophora gigantea*, *Polyporus anceps*, and *Polyporus abietinus*, accounted for over 80 per cent of the isolations. It is also evident that *Fomes pinicola* was the most frequently encountered brown sap rot, accounting for almost half of the identified isolations made from this type of decay.

Figs. 18 and 19 illustrate the progressive changes in the frequency of occurrence of the sap-rotting fungi with each succeeding year up to five years after the fire. The apparent replacement of *F. pinicola* by *F. subroseus* in the brown sap rot complex of all three host species is quite striking.

Heart Rot

The rate of progress of heartwood decay in living trees varies, depending upon the specific fungus and host tree involved. Most investigations that have been carried out report a rate of about five inches annually in a longitudinal direction (16). Changes in the extent of heart rot, during the period in which the deterioration of dead trees is of economic importance, have been generally disregarded since it was assumed that the losses resulting from this extension were insignificant in comparison with those caused by other agents of deterioration.

All but one of the ten sample plots in this study were established in 140- or 160-year-old even-aged pine stands. Unpublished data collected in conjunction with the Ontario Department of Lands and Forests cull survey project indicate that, for jack pine in northern Ontario, the percentage of the total merchantable volume deducted because of heart rot increases from 17 to 21 per cent over the five-year period from 147 to 152 years of age. These figures are based on a sample of 1,500 jack pine trees from several regions of Ontario, including the Chapleau district. White (17), in a study of the decay relationships of white pine in the Temagami Lake and Ottawa Valley areas found that in this age class the percentage of the total merchantable volume deducted because of heart rot increased from 34.7 to 35.1 per cent over a similar five-year period. Although no comparable data are available for red pine, it would seem from the foregoing that the increase in heart rot volume in living red pine of this age group during a five-year period would be small.

The unexpected but pronounced increase in heart rot deductions that occurred in fire-killed jack, red, and white pine during the five-year interval following the fire is shown clearly in Fig. 20 and Table IV. The consistent increase observed in all three species is significantly higher than one would expect to find in living trees over the same period. It is postulated that changes in the heartwood owing to the death of these trees have in some

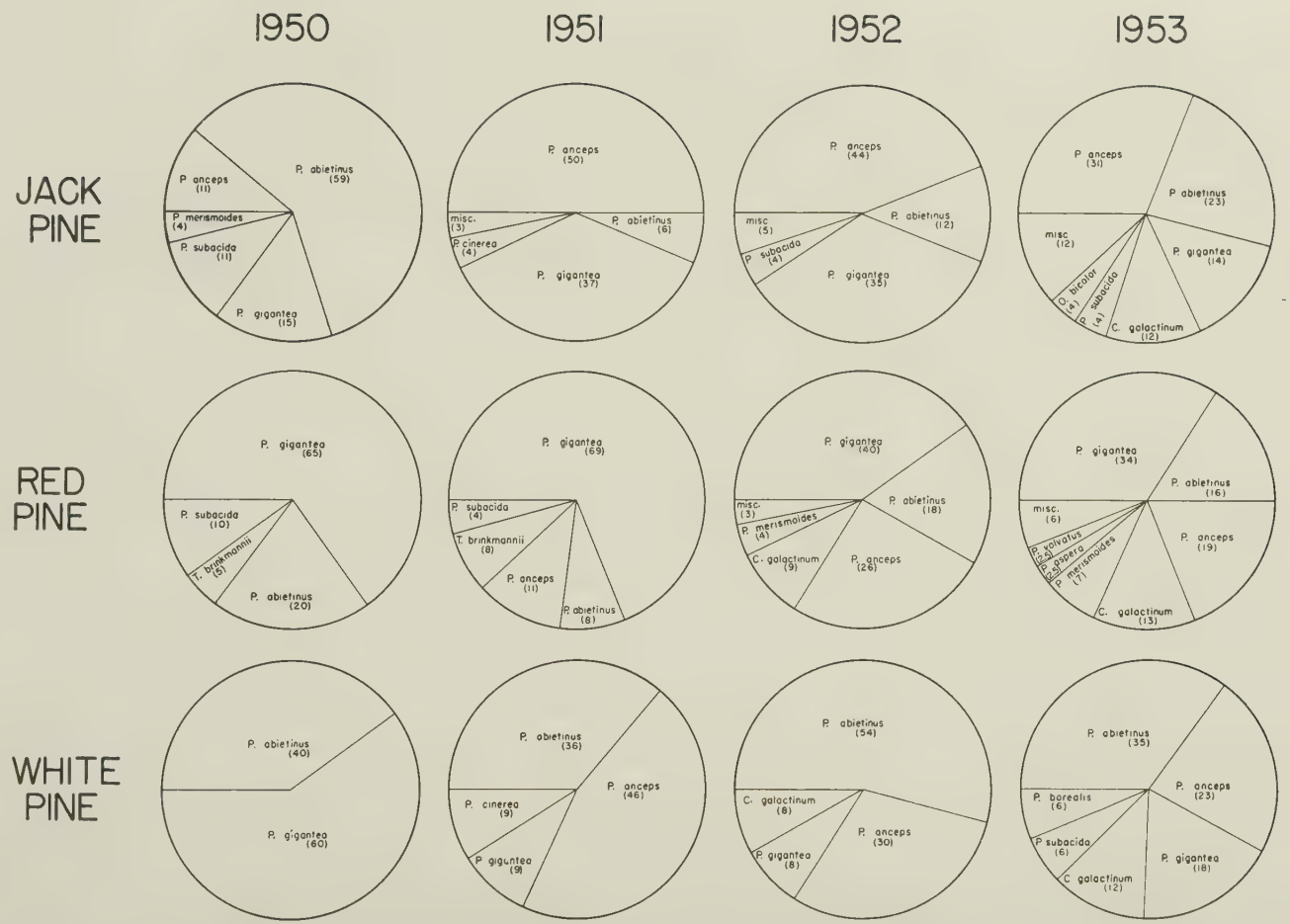


FIGURE 18. The progressive changes in the frequency with which various fungi were isolated from white sap rots of fire-killed pine between two and five years following the fire.

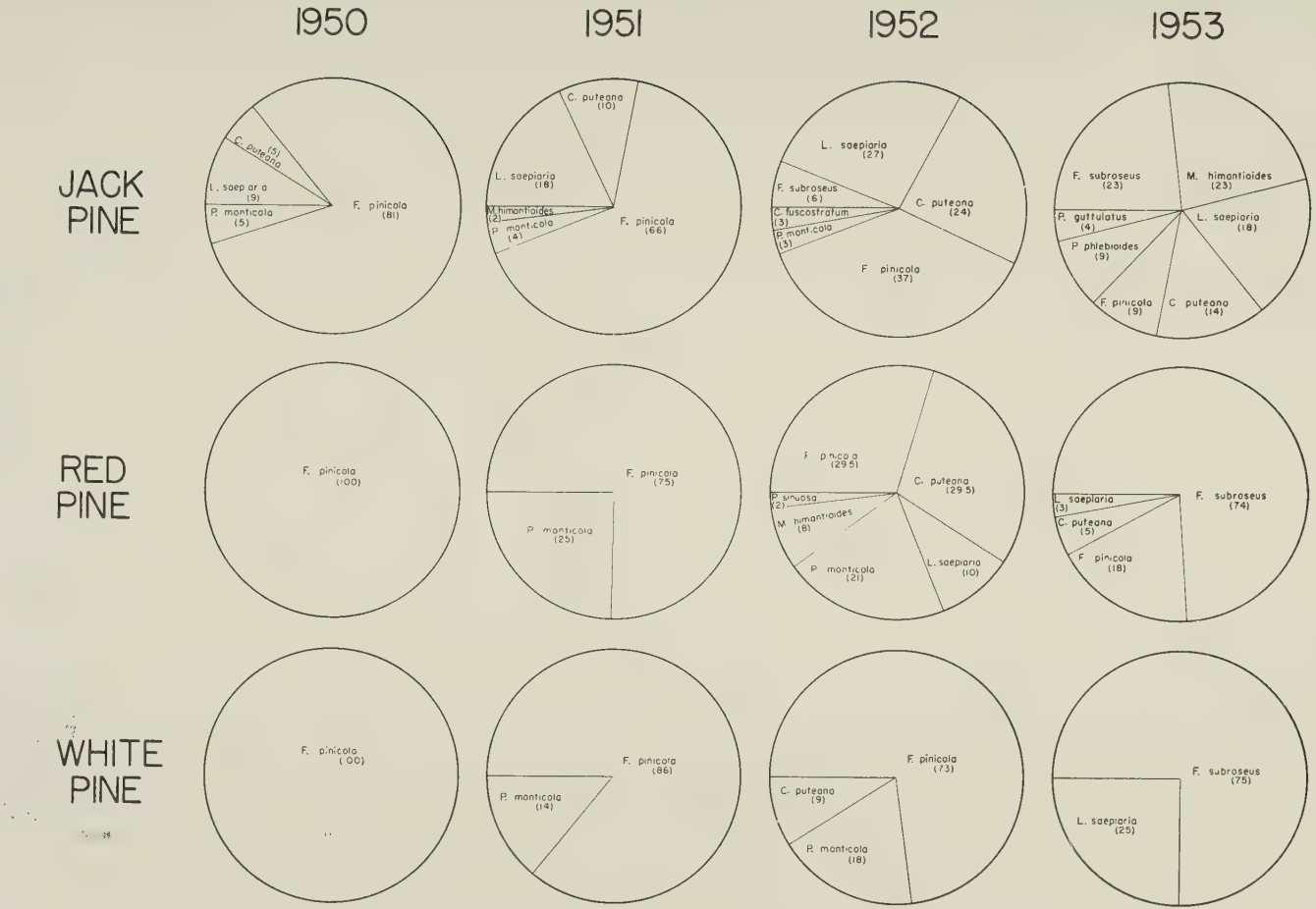


FIGURE 19. The progressive changes in the frequency with which various fungi were isolated from brown sap rots of fire-killed pine between two and five years following the fire.

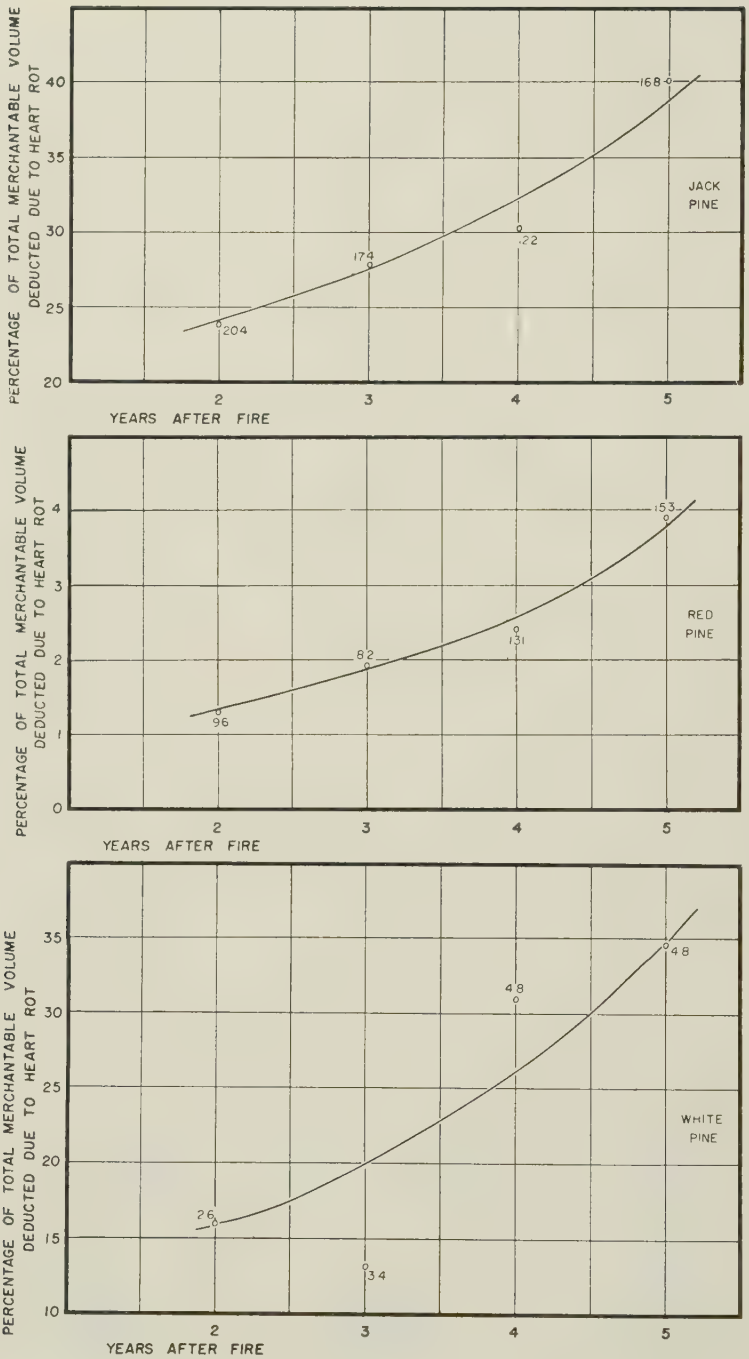


FIGURE 20. The increase in the percentage of the total merchantable volume deducted because of heart rot in dead jack, red and white pine during the five-year period following the fire.

TABLE IV

THE INCREASE IN HEART ROT DEDUCTIONS IN KILLED JACK, RED, AND WHITE PINE DURING THE FIVE YEARS FOLLOWING THE FIRE

Species	Number of years after fire	Number of killed trees	Total merchantable volume, bd. ft.	Heart rot deductions Ontario log rule, bd. ft.	Actual percentage of total merchantable volume deducted because of heart rot	Curved percentage of total merchantable volume deducted because of heart rot*	Percentages of total merchantable volumes deducted because of heart rot in excess of those applicable two years following the fire
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Jack pine.....	2	204	17,857	4,286	23.9	24.1	—
Jack pine.....	3	174	15,635	4,356	27.9	27.6	3.5
Jack pine.....	4	122	12,251	3,706	30.3	32.3	8.2
Jack pine.....	5	168	14,741	5,929	40.2	38.6	14.5
Red pine.....	2	96	14,674	189	1.3	1.3	—
Red pine.....	3	82	12,035	232	1.9	1.9	0.6
Red pine.....	4	131	20,626	490	2.4	2.6	1.3
Red pine.....	5	153	23,807	918	3.9	3.8	2.5
White pine....	2	26	4,790	760	15.9	15.9	—
White pine....	3	34	4,179	552	13.2	20.0	4.1
White pine....	4	48	8,745	2,700	30.9	26.2	10.3
White pine....	5	48	8,625	2,983	34.6	34.6	18.7

* Percentages read from curves in Fig. 20.

unknown manner provided a more suitable substrate for the heart rot fungi, thereby stimulating them to much faster growth, colonization, and destruction of the wood than occurs normally in living trees.

It seems reasonable, under these circumstances, that this abnormal increase in the rate of progress of heart rots should be included as a form of deterioration of these killed trees. It was assumed from the shape of the curves in Fig. 20 that the percentage of the total merchantable volume deducted because of heart rot two years after the fire can be considered the same as that which would have been deducted at the time the trees were killed. Thus the actual amount of heart rot deterioration is shown in column 8 of Table IV, which gives the percentages of the total merchantable volumes deducted because of heart rot each year in excess of those applicable two years following the fire.

Practically all of this increase in heart rot volume occurred in the trunk rots of these trees. The increase in the volume of butt rots was very slight. One fungus, *Fomes pini*, was isolated from over 80 per cent of the trunk rots of jack, red, and white pine. This form of deterioration, therefore, may be almost entirely attributed to the action of this organism. *Fomes pini* heart rot is illustrated in Figs. 16 and 17.

Factors That May Influence the Rate of Deterioration

Tree Growth Rate and Diameter

The radial growth in inches per decade at stump height for the last six decades before death was recorded for each tree. On the basis of these figures the trees were classified into three groups representing those with slow, medium,

and fast growth in the sapwood and outer heartwood. Since the trees sampled occurred in even-aged stands, it follows that in general those trees with relatively fast growth over the last 60 years before death would tend to be of greater diameter than those with a relatively slow growth rate. Table V indicates clearly that, in each of the three species of pine studied, a pronounced relationship exists between the average width of the annual rings in the outer bole and tree diameter.

TABLE V

THE RELATIONSHIP BETWEEN THE WIDTH OF ANNUAL RINGS IN THE OUTER BOLE, TREE DIAMETER, AND THE DEPTH OF RADIAL PENETRATION OF VISIBLE DETERIORATION

Species	Number of years after fire	Rings narrowly spaced (slow growth)			Rings moderately spaced (medium growth)			Rings widely spaced (fast growth)		
		Number of trees	Average diameter at breast height	Average depth of radial penetration of deterioration, inches	Number of trees	Average diameter at breast height	Average depth of radial penetration of deterioration, inches	Number of trees	Average diameter at breast height	Average depth of radial penetration of deterioration, inches
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Jack pine.	2	37	11.8	0.78	39	12.1	1.14	24	14.0	1.59
Jack pine.	3	24	10.1	1.13	38	12.7	1.43	23	14.6	1.77
Jack pine.	4	35	11.7	1.24	35	12.5	1.78	21	14.3	2.09
Jack pine.	5	18	11.9	1.65	40	12.3	2.02	30	13.4	2.12
Red pine..	2	22	12.5	2.05	37	13.3	3.04	30	16.2	4.06
Red pine..	3	37	12.7	2.39	32	13.8	3.00	6	14.6	3.60
Red pine..	4	38	12.5	2.68	47	13.9	3.81	46	15.5	4.72
Red pine..	5	24	12.7	3.03	48	13.3	3.52	45	14.0	4.52
White pine	2	6	12.6	1.27	3	15.4	1.44	5	16.8	2.52
White pine	3	5	13.7	2.08	7	13.2	1.49	11	13.5	2.18
White pine	4	11	14.4	2.19	11	14.4	2.75	16	15.9	3.39
White pine	5	14	12.9	2.06	8	16.1	2.85	4	18.5	3.90

Table V also shows that the average depth of radial penetration of visible deterioration is greatest in those trees with widely spaced annual rings in the outer bole, and least in those with narrowly spaced rings. This relationship is very pronounced in all three species of pine. A similar relationship was found by Kimmey and Furniss in an investigation of the deterioration of fire-killed Douglas fir (7). It is generally agreed (16) that fungi penetrate wood in which the annual rings are relatively close together at a slower rate than wood in which the rings are more widely separated. A logical explanation of this fact is found in a comparison of the number and thickness of cell walls that must be penetrated in slow-growing wood with the reduced number and thickness of those encountered in a similar distance in fast-growing wood.

It is possible that the thicker sapwood usually associated with fast growing trees provides an explanation of the relationship between growth rate and deterioration. Dead sapwood, because of its moist condition and relative lack of growth-inhibiting substances, constitutes a more favorable environment than heartwood for the growth and establishment of fungi. Larger trees possess more widely spaced annual rings and, as a rule, thicker sapwood than smaller trees of the same age class; radial penetration by deteriorating fungi is hence more rapid in larger trees, as shown in Table V.

TABLE VI

THE RELATIONSHIP BETWEEN TREE DIAMETER, SAP ROT, AND SAP STAIN IN FIRE-KILLED JACK PINE AND RED PINE

	Percentage of total merchantable volume occupied by sap stain				Percentage of total merchantable volume deducted because of sap rot			
Species	Jack pine		Red pine		Jack pine		Red pine	
Diameter classes*	9–11	13–18	9–12	14–21	9–11	13–18	9–12	14–21
Two years after fire	20.0	16.3	41.1	47.4	11.8	4.7	2.9	5.2
Three years after fire	26.2	20.9	38.7	40.6	15.3	17.5	18.3	14.6
Four years after fire	13.5	11.0	25.8	19.8	42.1	24.0	64.4	48.9
Five years after fire	4.3	0.3	6.0	7.2	68.0	24.4	85.5	68.0

* Diameter at breast height, outside bark.

Table VI shows the relationship between jack pine and red pine tree diameters, scaling deductions directly due to sap rot, and sap stain volume. This table shows that tree size had no significant effect upon these last two factors until a period of four years had elapsed after the fire; from this time on a larger percentage of sap stained volume and greater sap rot deductions occur in the smaller than in the larger trees, despite the faster rate of penetration of deteriorating fungi in the latter. The reason for this is that the greater volume of deterioration in larger trees is more than compensated for by the much greater volume of sound, merchantable wood recoverable from large trees compared with that recoverable from small trees four or five years after the fire.

TABLE VII

THE RELATIONSHIP BETWEEN THE SEVERITY OF BURN AND THE DEPTH OF RADIAL PENETRATION OF DETERIORATION IN FIRE-KILLED JACK PINE AND RED PINE

Species (1)	Number of years after fire (2)	Average depth of radial penetration of deterioration (inches)		
		Lightly burned trees (3)	Moderately burned trees (4)	Severely burned trees (5)
Jack pine	2	1.0	1.1	1.4
Jack pine	3	1.9	1.6	1.4
Jack pine	4	1.8	1.7	1.6
Jack pine	5	2.6	2.5	2.1
Red pine	2	3.0	3.4	2.8
Red pine	3	2.7	2.9	2.6
Red pine	4	3.5	3.8	4.0
Red pine	5	3.8	4.0	3.9

Degree of Burn

In Table VII the jack pine and red pine trees have been classified according to the degree of burn based on the condition and appearance of the trunk and crown. In cases where the trunk was lightly to moderately charred with bark intact, the branches relatively undamaged, and many dead needles retained, the trees were considered lightly burned. Trees with trunk and branches heavily charred, the bark entirely or almost entirely removed, and no foliage remaining, were classed as severely burned. Those trees with medium burn characteristics that could not be placed in either of the above two categories were regarded as moderately burned.

The average depth of radial penetration of visible deterioration of lightly, moderately, and severely burned jack pine and red pine at various periods after the fire is presented in Table VII, and is shown graphically in Fig. 21. It is evident that there is no consistent difference in the rate of deterioration of jack pine and red pine that have been subjected to various degrees of burn. From three to five years following the fire, lightly burned jack pines appear to deteriorate slightly faster than moderately burned trees, which in turn deteriorate slightly faster than severely burned trees. With the red pine the situation is reversed, and lightly burned trees have the slower rate of deterioration.

In all cases, the differences in the average depth of visible deterioration among trees of varying degree of burn were very small, and not statistically significant. It is considered likely that the apparent differences in the rate of deterioration in lightly, moderately, and severely burned trees may be accounted for by chance alone, and that the degree of burn actually had little or no effect upon this rate.

In previous investigations of the deterioration of fire-killed trees, fairly conclusive evidence has been developed to indicate that the amount and rate of deterioration tend to decrease as the severity of burn increases. The explanation given is that a light burn often leaves the bark intact on the tree whereas a heavy burn removes it, with the result that lightly burned trees possess moister wood which provides more favorable conditions for the growth and establishment of deteriorating fungi. One possible reason why this relationship does not exist in jack pine and red pine killed in the Mississagi fire is that the lightly and severely burned trees of this investigation were not so divergent in degree of burn as those encountered in other studies.

The Deterioration of Jack, Red, and White Pine Trees

One year after the fire 34 white pine and 59 red pine were examined for pathological deterioration at Lake Kindiogami. It soon became apparent that the only type of pathological deterioration present at that time was a blue sapwood stain. Observations made of a few representative jack pine indicated that the same condition existed in this species. On the basis of the uniformity observed in these trees, it was decided that this sample would provide an

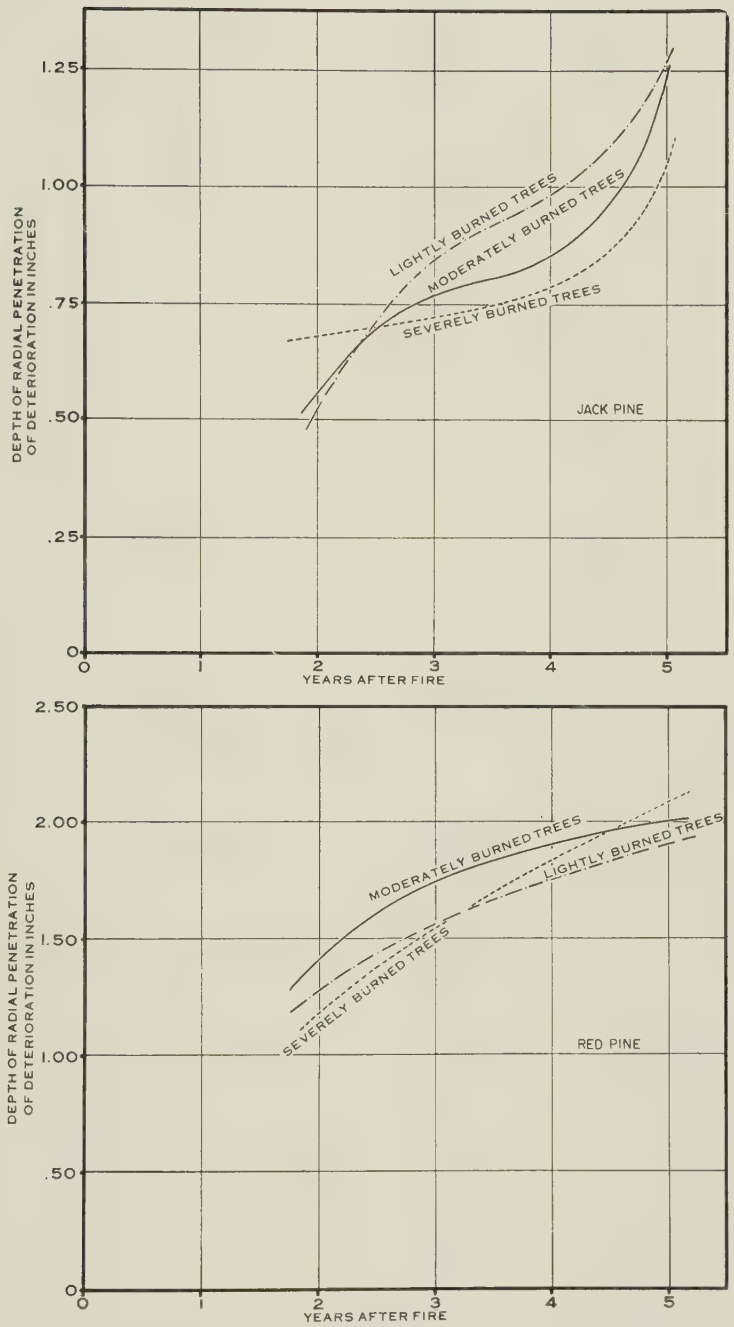


FIGURE 21. The effect of the severity of burn of fire-killed jack pine and red pine on the rate of radial penetration of visible fungal deterioration.

TABLE VIII

ACTUAL VOLUMES OF HEART ROT AND OF VARIOUS KINDS OF DETERIORATION IN DEAD JACK, RED, AND WHITE PINE AT DIFFERENT INTERVALS FOLLOWING THE FIRE

Species	Number of years after fire	Number of killed trees	Average diameter at breast height	Total volume of trees (cu. ft.)	Total merchantable volume (cu. ft.)	Percentage of merchantable volume occupied by heart rot	Percentage of merchantable volume destroyed by fire	Percentage of merchantable volume occupied by sap stain	Percentage of merchantable volume occupied by sap rot	Percentage of merchantable volume actually deteriorated, including heart rot increase	Curved percentage of merchantable volume deteriorated*
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Jack pine.....	2	204	11.3	5178.5	3192.8	13.4	1.9	18.2	2.5	22.6	22.0
Jack pine.....	3	174	11.6	4304.8	2758.0	15.0	1.4	22.5	6.3	31.8	31.1
Jack pine.....	4	122	12.0	3383.3	2261.3	17.1	0.3	10.9	18.6	33.5	35.5
Jack pine.....	5	168	11.9	4132.1	2557.6	23.9	0.8	1.5	34.6	47.4	46.7
Red pine.....	2	96	14.1	4122.4	3372.2	0.4	0.1	46.5	1.5	48.1	38.5
Red pine.....	3	82	13.3	2759.2	2144.0	1.0	0.1	35.5	5.6	41.8	52.0
Red pine.....	4	131	14.1	4681.1	3824.2	1.1	—	20.0	36.5	57.5	57.5
Red pine.....	5	153	13.5	5062.5	4153.5	1.6	—	6.2	51.1	58.6	58.9
White pine.....	2	26	14.9	1115.1	800.5	8.9	—	27.5	0.4	27.9	27.9
White pine.....	3	34	13.3	1037.3	752.1	7.0	0.7	25.0	7.4	31.2	35.8
White pine.....	4	48	14.5	1841.2	1519.1	17.0	—	14.2	25.6	47.9	43.9
White pine.....	5	48	14.4	1677.8	1305.7	21.3	—	1.7	39.7	53.8	54.3

*Percentages read from curves in Figs. 22, 23 and 24.

adequate estimate of the amount of blue stain to be expected in red and white pine approximately one year after the fire.

Blue stain was found in 88.2 per cent of the white pine and 74.6 per cent of the red pine examined, usually in the form of patches or streaks in the outer sapwood. The average depth of radial penetration of blue stain was 0.9 in. in white pine and 0.4 in. in red pine. The more extensive blue stain in white pine than in red pine at this time, along with the greater insect damage that was observed in the former species, corroborates the results of the mill study conducted by Prebble (11).

The changes that occurred in the actual volumes of heart rot and of various kinds of deterioration in fire-killed jack, red, and white pine from two to five years following the death of the trees are summarized in Table VIII. The progressive volumetric deterioration during the five-year period following the

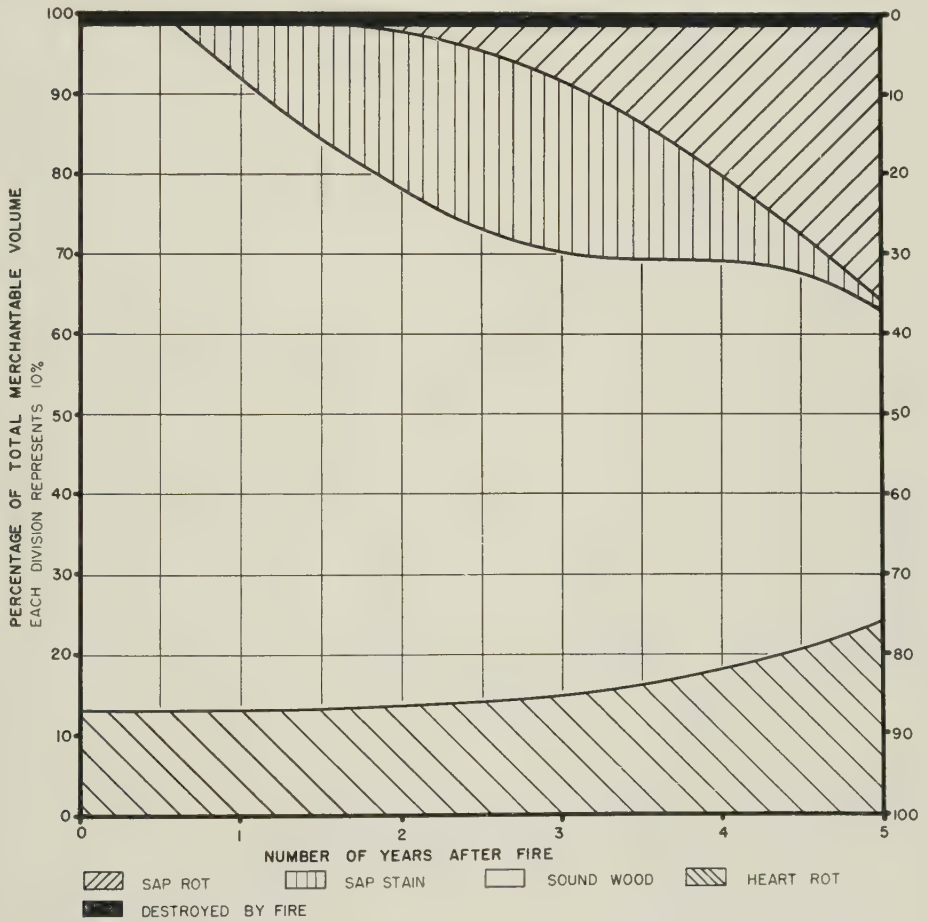


FIGURE 22. The progressive deterioration of fire-killed jack pine trees during the five-year period following the fire.

fire is illustrated separately for each of the three species in Figs. 22, 23, and 24. It is evident from these figures that the progress of deterioration follows the same general pattern in all three species. The only noticeable differences are in the volumes of heart rot and in the volumes of wood destroyed by the fire.

As the interval following the fire lengthened, the volume of heart rot in the trees increased at a progressively greater rate. This is illustrated in Figs. 22, 23, and 24. Sap stain, but no sap rot, occurred in the sapwood one year after the fire. One year later most of the sapwood was stained. The volume of wood occupied by sap stain increased very little, if at all, after that time. The reason for this is probably that the sap stain organisms remain viable only in relatively moist wood which contains the remnants of the cell contents.

A small proportion of the volume of each species was affected by sap rot two years after the fire. It occurred at this time in the form of small patches in the outer sapwood. In succeeding years, sapwood deterioration consisted

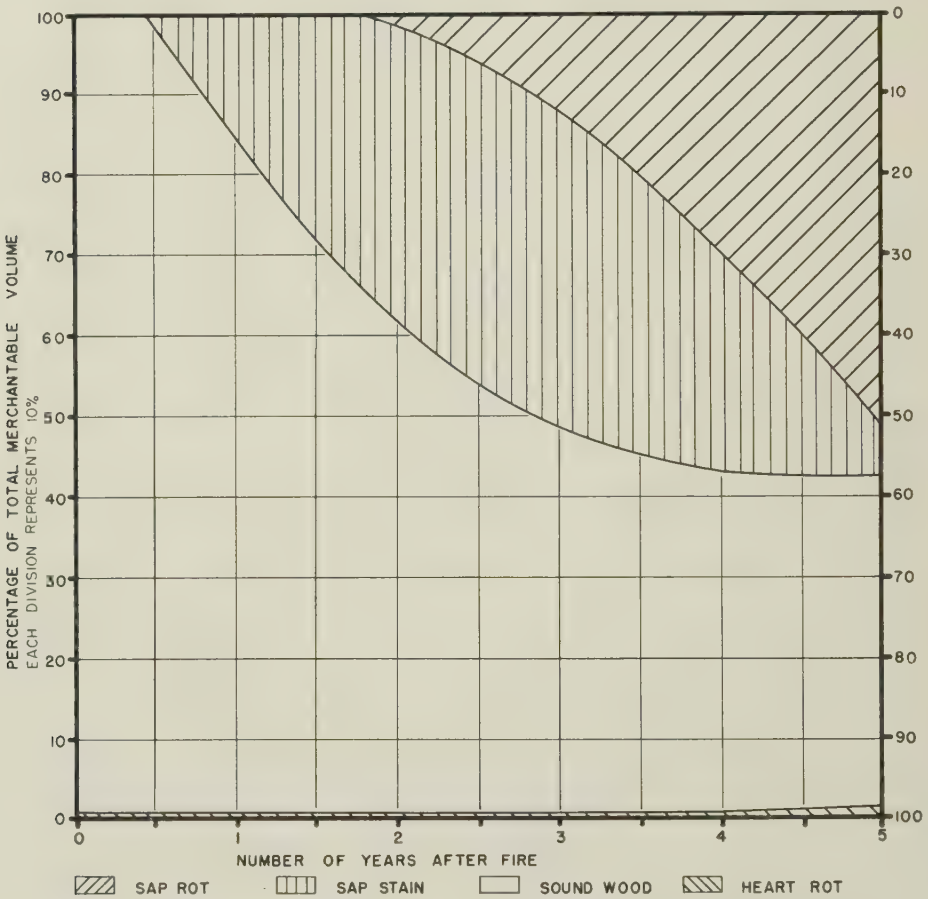


FIGURE 23. The progressive deterioration of fire-killed red pine trees during the five-year period following the fire.

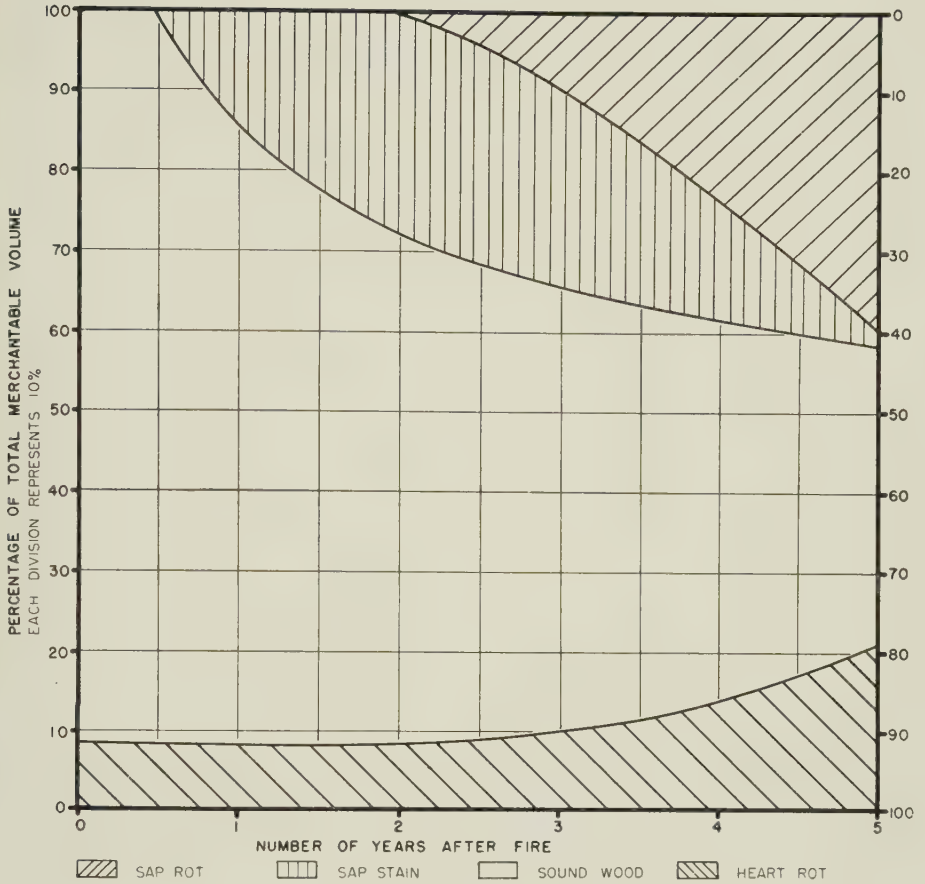


FIGURE 24. The progressive deterioration of fire-killed white pine trees during the five-year period following the fire.

of the continuous replacement of existing sap stain by sap rot. Very little sap stain remained in these trees five years after the fire and a few trees with sap rot extending short distances into the heartwood were encountered at this time.

The progressive increase in the percentage of the merchantable volume occupied by sap rot following the fire is the most significant factor in the reduction of the recoverable merchantable volume of the fire-killed jack, red, and white pine. Fig. 25 has been constructed to provide a direct comparison of this factor among these three species.

The Deterioration of Jack Pine and Red Pine Stands

A timber operator who is confronted by the task of salvaging large areas of fire-killed timber undoubtedly will be more concerned with the total deterioration of entire stands than with the deterioration characteristics of each species represented in those stands. More specifically, he will be eager

to acquire knowledge concerning the reduction in the recoverable volume of wood per acre at various periods after the fire as an aid in determining the economic feasibility of salvage operations. The sample plots that are the basis for this study are considered representative of extensive jack pine and

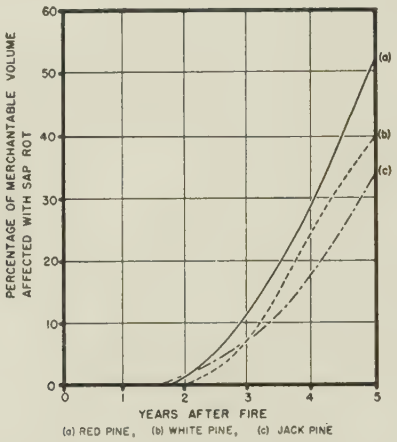


FIGURE 25. The increase in the percentage of the merchantable volume of fire-killed jack, red, and white pine containing sap rot during the five-year period following the fire.

red pine stands which occurred in the Mississagi fire area. Tables IX and X show the progressive reduction in the recoverable volume per acre in these stands, in which the losses due to wood consumed by fire, sap rot, and extension of heart rots are considered individually. Figs. 26 and 27 illustrate the changes

TABLE IX

THE EFFECTS OF EXCESSIVE HEART ROT INCREASE, CONSUMED WOOD, AND SAP ROT IN THE REDUCTION OF THE MERCHANTABLE VOLUME OF FIRE-KILLED JACK PINE AND RED PINE STANDS, BASED ON COMPLETE MORTALITY

Type of stand (predominant species)	Number of years after fire	Number of trees sampled				Percentage of net merchantable volume deducted because of excessive heart rot increase*	Percentage of net merchantable volume deducted because of wood consumed by fire**	Percentage of net merchantable volume deducted because of sap rot	Total percentage of net merchantable volume deducted because of deterioration
		Jack pine	Red pine	White pine	Total				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Jack pine.....	2	200	0	11	211	—	2.1	7.9	10.0
Jack pine.....	3	175	0	15	190	4.6	2.1	24.9	31.6
Jack pine.....	4	111	0	14	125	11.1	2.1	33.2	46.4
Jack pine.....	5	153	0	13	166	19.5	2.1	40.2	61.8
Red pine.....	2	5	101	17	123	—	0.1	3.3	3.4
Red pine.....	3	2	89	23	114	1.2	0.1	11.9	13.2
Red pine.....	4	11	159	37	207	3.6	0.1	41.8	45.5
Red pine.....	5	15	166	36	217	6.8	0.1	63.3	70.2

* Based on percentage increases by species, column 8, Table IV.

** Average percentages over the entire four-year period computed for jack pine and red pine stands.

TABLE X

THE PROGRESSIVE REDUCTION IN THE RECOVERABLE MERCHANTABLE VOLUME PER ACRE OF FIRE-KILLED JACK PINE AND RED PINE STANDS, BASED ON COMPLETE MORTALITY

Type of stand (predominant species) (1)	Number of years after fire (2)	Total acreage sampled (3)	Number of trees (4)	Average diameter at breast height (5)	Total merchantable volume, bd. ft. (6)	Volume deducted because of heart rot present at time of fire, Ontario log rule, bd. ft.* (7)	Net merchantable volume before fire, bd. ft. (8)	Recoverable volume per acre before the fire, bd. ft. (9)	Percentage of net merchantable volume deducted because of deterioration** (10)	Recoverable volume per acre after the fire, bd. ft.*** (11)	Percentage of recoverable merchantable volume occupied by sap stain (12)	Percentage of original net merchantable volume that can be salvaged (13)
Jack pine	2	2.25	211	11.5	18,717	4,369	14,348	6,377	10.0	5,400	18.7	90.0
Jack pine	3	2.25	190	11.7	17,331	4,038	13,293	5,908	31.6	4,104	18.5	68.4
Jack pine	4	1.75	125	12.1	13,513	3,051	10,462	5,978	46.4	3,216	11.7	53.6
Jack pine	5	2.00	166	11.9	14,556	3,365	11,201	5,600	61.8	2,292	2.4	38.2
Red pine	2	1.50	123	14.1	25,143	1,017	24,126	16,084	3.4	15,939	41.6	96.6
Red pine	3	1.00	114	13.3	16,908	692	16,216	16,216	13.2	14,322	37.2	86.8
Red pine	4	2.00	203	14.1	35,232	1,834	33,418	16,709	45.5	8,993	18.1	54.5
Red pine	5	2.00	217	13.7	35.032	1,951	13,081	16,540	70.2	4,917	4.7	29.8

*Deductions taken from curves in Fig. 20, i.e. 24.1 per cent of the total merchantable volume of jack pine, 1.3 per cent of the total merchantable volume of jack pine, 15.9 per cent of the total merchantable volume of jack pine.

**Taken from column 10, Table IX.

***Based on column 9 which indicates an average of roughly 6,000 bd. ft. per acre recoverable from jack pine stands before the fire, and roughly 16,500 bd. ft. per acr recoverable from red pine stands before the fire.

in the percentage of the total merchantable volume deducted due to various causes in the five-year period following the fire in jack pine and red pine stands, respectively.

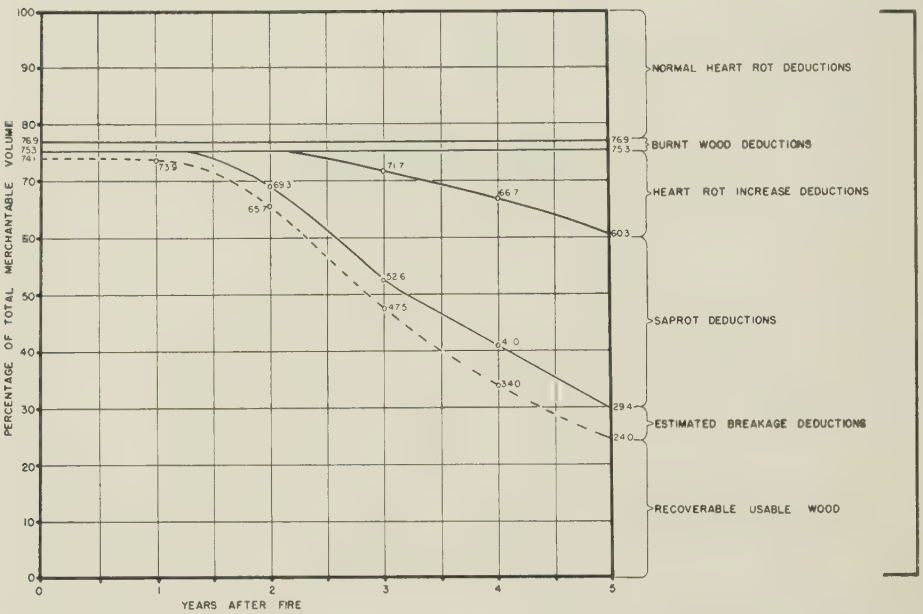


FIGURE 26. The progressive changes in the percentages of the total merchantable volume of fire-killed jack pine stands deducted for various causes during the five-year period following the fire.

Fig. 28 illustrates the reduction in the recoverable merchantable volume per acre of fire-killed jack pine and red pine stands during the five-year period following the fire. When more than two years have elapsed after a fire in this type of stand, it is evident that this reduction, caused by fungal deterioration, will be a major consideration in the determination of the feasibility of salvage operations. The reasons for the reluctance of operators to undertake logging operations in white pine stands two years or more following the fire have already been discussed.

The percentage of the net merchantable volume of jack pine and red pine stands at the time of the fire, recoverable at yearly intervals following the fire, is shown in column 13 of Table X. Column 12 indicates the percentage of this recoverable volume that may be expected to contain sap stain, so that an estimate can be made of the extent of degrade in timber salvaged from these stands at different periods following the fire.

Only two of the 77 merchantable pine trees in the sample plots that were not killed in the year of the fire, died during the course of the investigation. The problem of trees dying from two to five years after the fire was for this reason ignored, and when the sample plots were established the trees were

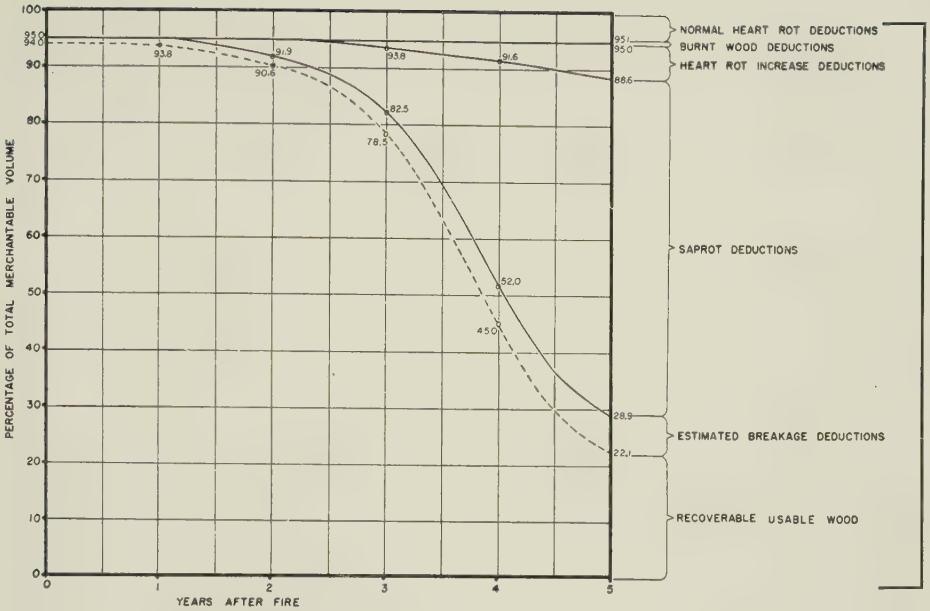


FIGURE 27. The progressive changes in the percentages of the total merchantable volume of fire-killed red pine stands deducted for various causes during the five-year period following the fire.

classified as either killed outright or living. The proportion of surviving trees encountered was 0.6 per cent of jack pine, 10.3 per cent of red pine, and 6.0 per cent of white pine trees.

Considerable variation existed in the ratio of surviving trees to killed trees in burned over areas. Lightly burned stands with an estimated 30 per cent survival of merchantable pine were occasionally observed, whereas living trees were seldom found in severely burned stands. Furthermore, the sporadic nature of the fire left numerous scattered patches of living timber which, to avoid waste, were cut together with the killed trees. From the foregoing it is evident that one would expect endless variations in the proportion of living trees of each species of pine cut in different operations in the Mississagi fire region. It is extremely unlikely that the proportion of living trees encountered in the sample plots would correspond to that encountered in an actual operation. The deterioration losses determined for the sample plots therefore had to be modified to make these figures applicable to operations in which varying ratios of living to dead trees are encountered.

By adjusting the sample plot deterioration figures to represent the situation that would have existed if all merchantable trees had been killed at the time of the fire, a uniform basis was secured from which losses could be calculated in stands with varying proportions of living trees. This was accomplished by increasing the deterioration losses of jack pine and red pine stands at different periods following the fire by the corresponding percentages

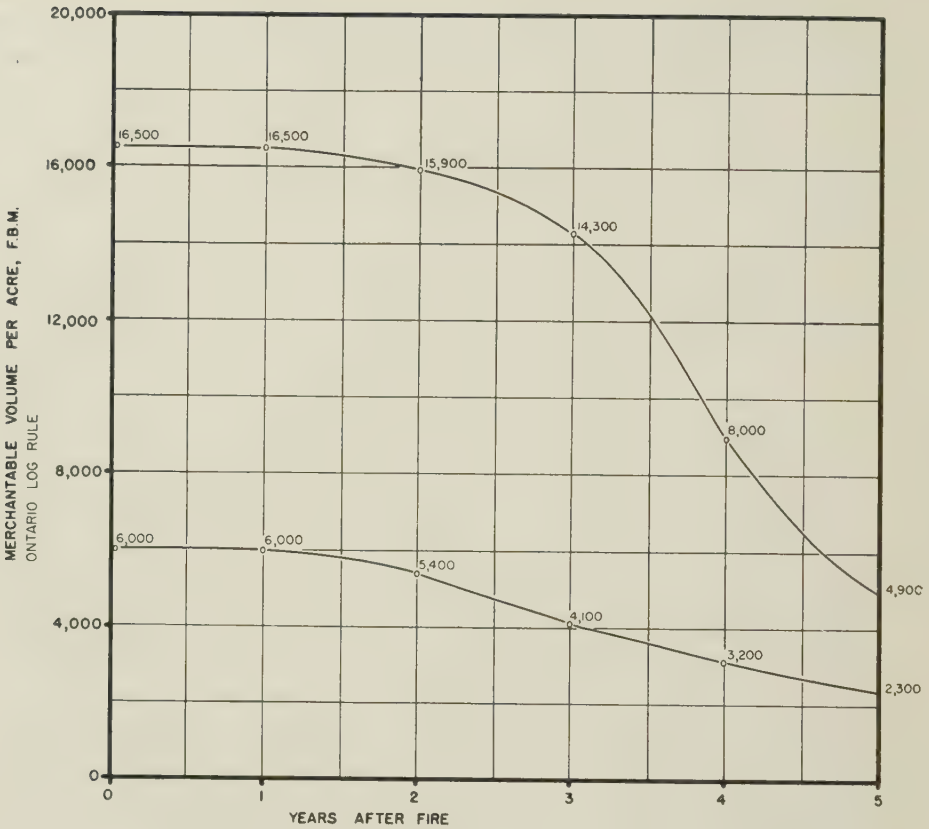


FIGURE 28. The progressive reduction in the merchantable volume of fire-killed jack pine (lower curve) and red pine stands during the five-year period following the fire.

of the total merchantable volume represented by living trees. Tables IX and X and Figs. 26, 27, and 28 therefore represent the deterioration of jack pine and red pine stands in which all pine trees of merchantable size are assumed to have died at the time of the fire.

Before commencing a felling operation, most operators know approximately the proportion of the original merchantable volume of pine that escaped death at the time of the fire in the areas in which they are about to conduct operations. By reducing accordingly the percentage of the merchantable volume deducted because of deterioration shown in column 10 of Table X, the reduction in the merchantable volume for the areas in question can be obtained.

The case of an operator who plans to salvage an area composed largely of red pine stands three years following a fire may be cited. From column 10 of Table X he notes that a reduction of 13.2 per cent of the original net merchantable volume would occur had all merchantable pine trees been killed outright at the time of the fire. The operator knows that approximately 20 per cent of the original merchantable volume of pine on the area in question

is composed of living trees. He must, therefore, reduce the percentage of 13.2 by 20 per cent, i.e. to 10.6 per cent which is the over-all reduction in merchantable volume based on the Ontario Log Rule that he should anticipate.

Column 12 of Table X reveals that about 37 per cent of the volume of his salvaged timber will contain sap stain.

Pulpwood Losses in Fire-Killed Jack Pine

Although this study was primarily designed to determine the effects of fungal deterioration on sawlogs salvaged from fire-killed pine stands, it was felt that any collateral information obtained concerning jack pine pulpwood losses should be included here. Table XI shows the reduction in the percentage of the original net merchantable volume of jack pine recoverable as pulpwood at various periods following the fire. No deductions were made for stained wood that was not soft or punky. For this reason a lower quality of finished product may result from the use of fire-killed timber.

The figures in Table XI are based entirely upon trees cut to sawlog specifications, i.e. to top diameters of 8 in. inside bark. In a pulpwood operation, trees usually are utilized to a top diameter of 3 in. These small pulpwood bolts ranging from 3 to 8 in. in diameter which were not examined in this study would have a greater proportion of their volume affected than the large logs represented in Table XI. To obtain more realistic figures for losses in pulpwood operations, the recoverable volume percentages in the last column of Table XI should be reduced, on the basis of previous studies, by an estimated 3 to 5 per cent.

In an investigation of the rate of deterioration of fire-killed spruce, balsam, and jack pine pulpwood in Quebec, Skolko (13) found a much slower rate of deterioration of jack pine than that encountered in this study. No simple explanation of these different results can be given at present. It may be postulated, however, that the fires in Quebec occurred in the late summer or fall, and that the killed trees had dried out sufficiently by the following spring to inhibit deterioration effectively. Another possible explanation is that drier conditions prevailed generally during the five years following the fires on the Quebec plots compared with those prevailing over a corresponding period on the Mississagi plots.

Discussion

The unexpected but striking difference in the rate of increase in volume of heart rot in fire-killed pine compared with that in living trees raises the question of whether or not this form of deterioration is a major factor in any study of the deterioration of dead trees. A similar, but less pronounced, relationship was observed in an investigation of the rate of deterioration of balsam fir trees killed as a result of spruce budworm epidemics (2). It may be that balsam fir trees with extensive heart rot are more susceptible to the detrimental effects of spruce budworm defoliation, and hence succumbed earlier than sound trees in the same stands. The difference in the rate of increase in volume of heart

TABLE XI

THE REDUCTION IN THE RECOVERABLE MERCHANTABLE VOLUME OF PULPWOOD FROM FIRE-KILLED JACK PINE AT VARIOUS PERIODS FOLLOWING THE FIRE

Number of years after fire	Number of trees	Total merchantable volume, cubed pulpwood (cu. ft.)	Heart rot deductions cubed pulpwood (cu. ft.)	Percentage of total merchantable volume deducted because of heart rot	Percentage of total merchantable volume deducted because of heart rot in excess of that applicable two years following the fire (deterioration)	Sap rot deductions, cubed pulpwood (cu. ft.)	Percentage of total merchantable volume deducted because of sap rot deterioration	Percentage of total merchantable volume deducted because of both forms of deterioration	Percentage of original net merchantable volume recoverable
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2	199	2875.7	488.4	17.0	—	187.5	6.5	6.5	93.5
3	172	2619.6	519.8	19.8	2.8	262.6	10.0	12.8	87.2
4	107	1821.0	389.2	21.3	4.3	334.9	18.4	22.7	77.3
5	147	2084.5	704.6	33.8	16.8	616.0	29.5	46.3	53.7

rot in living and dead trees could be more accurately ascertained in future deterioration studies. This would involve, during each year of investigation, the felling and examination of several living trees of the same age class in proximity to the dead trees under examination.

Obviously, it is essential that an appraisal of both fungal and insect damage be made when determining the feasibility of carrying out profitable salvage operations under existing economic conditions. Kimmey and Furniss (7) state, "Insects . . . characteristically cause only partial deterioration, as the affected wood is potentially usable as low-grade lumber unless otherwise degraded." Furthermore, significant insect activity in killed timber usually terminates within two years, so that although the resultant defects, principally borer tunnels, remain, further deterioration is almost entirely pathological. Nevertheless, the lowering of grade, and hence of value, caused by insect damage and sap stain appears to be of greater economic significance than the reduction in yield of merchantable timber per acre because of wood consumed by fire and sap rot, for the two or three years immediately following the fire.

This study has defined actual reductions in recoverable merchantable volumes per acre in fire-killed pine stands. It has demonstrated that, when more than two years have elapsed, reductions in yield of considerable magnitude due to deterioration as a direct or indirect result of fire occur in jack pine and red pine stands. The approximate percentages of the merchantable, recoverable volume of jack pine and red pine stands in this region affected by sap stain, at different intervals following the fire, have also been determined. Information concerning the reduction in value of salvaged wood has been presented in a mimeographed report of the Forest Insect Laboratory, Sault Ste. Marie (11), and other reports covering various aspects of entomological deterioration are expected. These reports in combination with this paper will complete the comprehensive picture of deterioration in fire-killed jack, red, and white pine.

Acknowledgments

During the course of this study assistance was received from the following: Dr. L. T. White, Forest Pathology Laboratory, Maple; Dr. M. K. Nobles, Botany and Plant Pathology Laboratory, Ottawa; the Ontario Department of Lands and Forests; the Forest Insect Laboratory, Sault Ste. Marie; and the R. F. Tétreault and Kormak Lumber Companies. The help given is gratefully acknowledged.

References

1. Anonymous. Cause and prevention of blue stain in wood. U.S. Div. Forest Pathology. Tech. Note 225, 1941.
2. Basham, J. T. The pathological deterioration of balsam fir killed by the spruce budworm. Pulp and Paper Mag., Canada, 52(9) : 120–134. 1951.
3. Boyce, J. S. Forest pathology. McGraw-Hill Book Company Inc., New York. 1948.
4. Bradner, M. and I. V. Anderson. Fire damaged logs—what is the loss? Timberman, 31 : 38–44. 1930.
5. Dance, B. W. and J. T. Basham. Interim report on the pathological deterioration of fire-killed pine in the Mississagi region of Ontario. (Mimeo. Rept.). Can. Dept. Agr., Sci. Serv., Forest Biol. Div., Maple, Ont. 1953.

6. Hepting, G. H. Prediction of cull following fire in Appalachian oaks. J. Agr. Research, 62 : 109–120. 1941.
7. Kimmey, J. W. and R. L. Furniss. Deterioration of fire-killed Douglas fir. U.S. Dept. Agr. Tech. Bull. 851. 1943.
8. Knapp, J. B. Fire-killed Douglas fir: a study of its rate of deterioration, usability and strength. U.S. Dept. Agr. Forest Serv. Bull. 112. 1912.
9. Leach, J. G., L. W. Orr, and C. Christensen. The interrelationships of bark beetles and blue-staining fungi in felled Norway pine timber. J. Agr. Research, 49 : 315-341. 1934.
10. Lindgren, R. M. Temperature, moisture, and penetration studies of wood-staining Ceratostomellaceae in relation to their control. U.S. Dept. Agr. Tech. Bull. 807 : 1–35. 1942.
11. Prebble, M. L. and R. F. Fytche. Degrade in fire-killed pine in the Mississagi area of Ontario. Forest Insect Laboratory, Sault Ste. Marie, Ont. (Unpublished Rept.). 1950.
12. Richmond, H. A. and R. R. Lejeune. The deterioration of fire-killed white spruce by wood-boring insects in northern Saskatchewan. Forestry Chron. 21 : 168–192. 1945.
13. Skolko, A. J. Deterioration of fire-killed pulpwood stands in Eastern Canada. Forestry Chron. 23 : 128–145. 1947.
14. Spaulding, P. and T. C. Scheffer. Minimizing losses by sap stain and decay in wind-thrown timber. U.S. Dept. Agr. (Mimeo.). 1939.
15. Verrall, A. F. Dissemination of fungi that stain logs and lumber. J. Agr. Research, 63 : 549–558. 1941.
16. Wagener, W. W. and R. W. Davidson. Heart rots in living trees. Bot. Review, 20 : 61–134. 1954.
17. White, L. T. Studies in forest pathology. X. Decay of white pine in the Timagami Lake and Ottawa Valley areas. Can. J. Botany, 31 : 175–200. 1953.

EDMOND CLOUTIER, C.M.G., O.A., D.S.P.
QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1958